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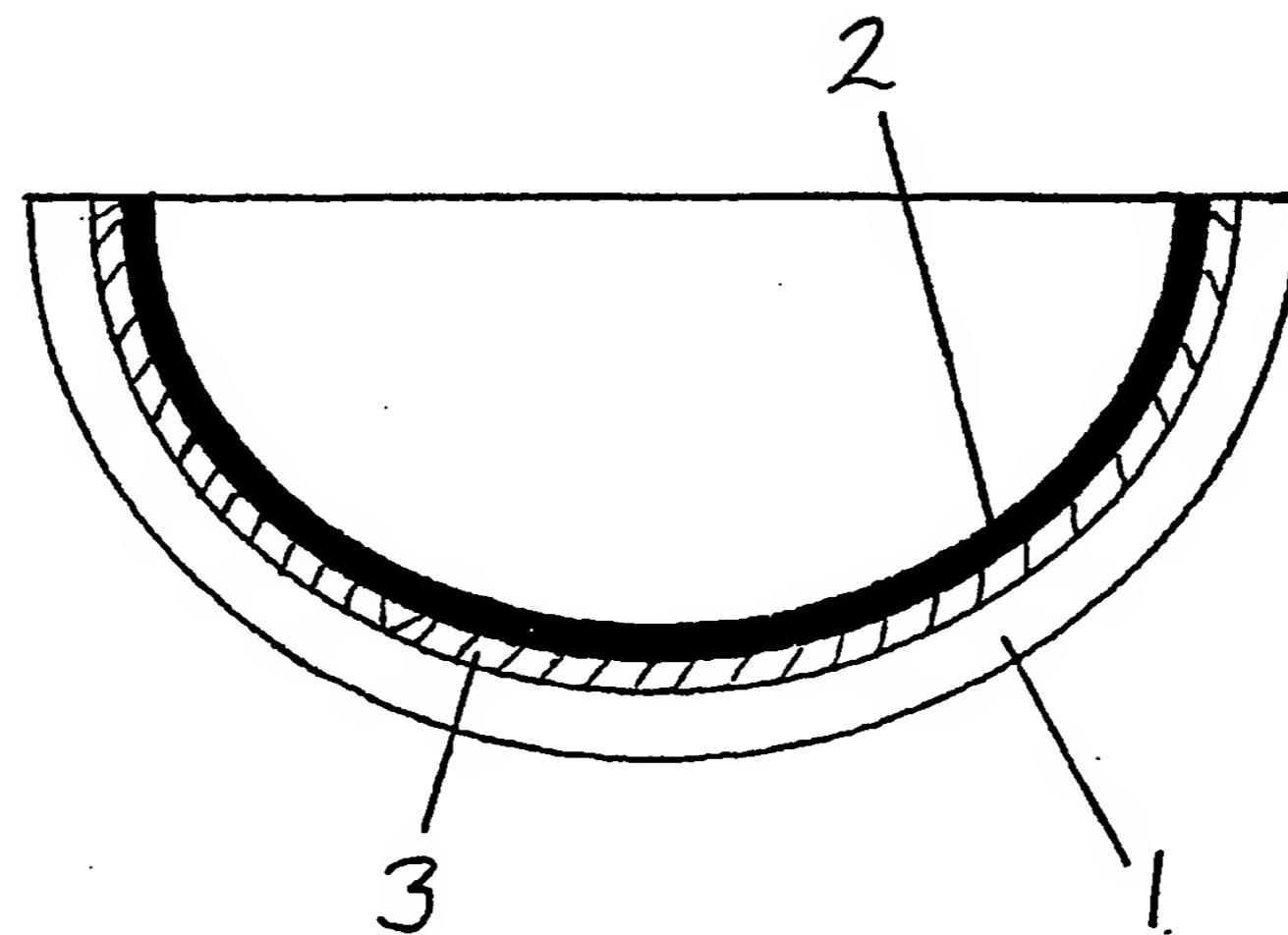
(54) Photosensitive switch

(57) The switch described uses interdigitated indium and silver electrodes closely spaced on the surface of a photosensitive semiconductor and an intense source of light such as a xenon flashlamp. The semiconductor and electrodes may be arranged on the surface inner of a hollow spherical cavity at the centre of which is the light source. The switch is designed to carry high currents (typically 10A) at relatively low voltages (typically 5kV).

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Figure 1



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**Figure 2**

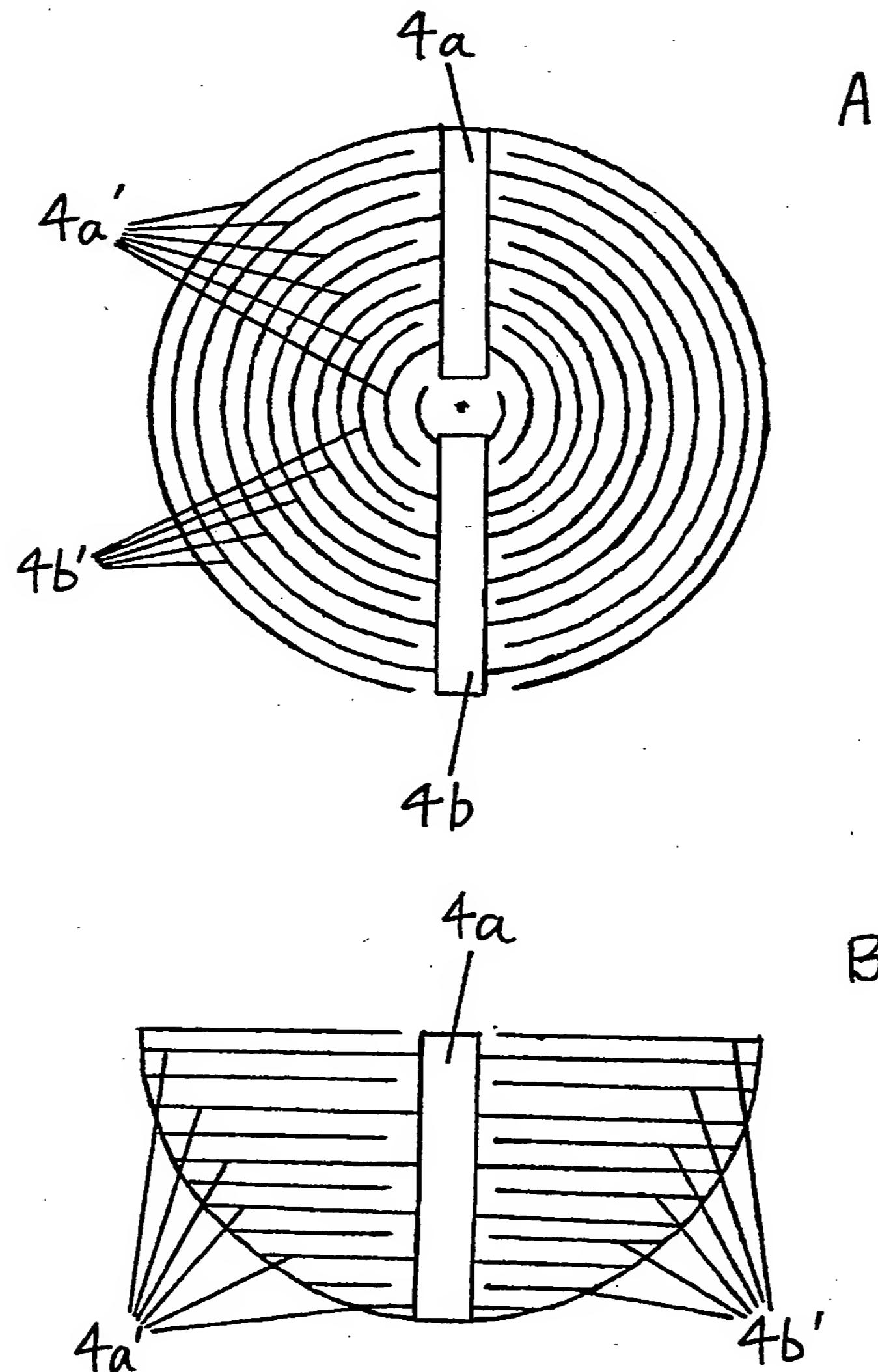
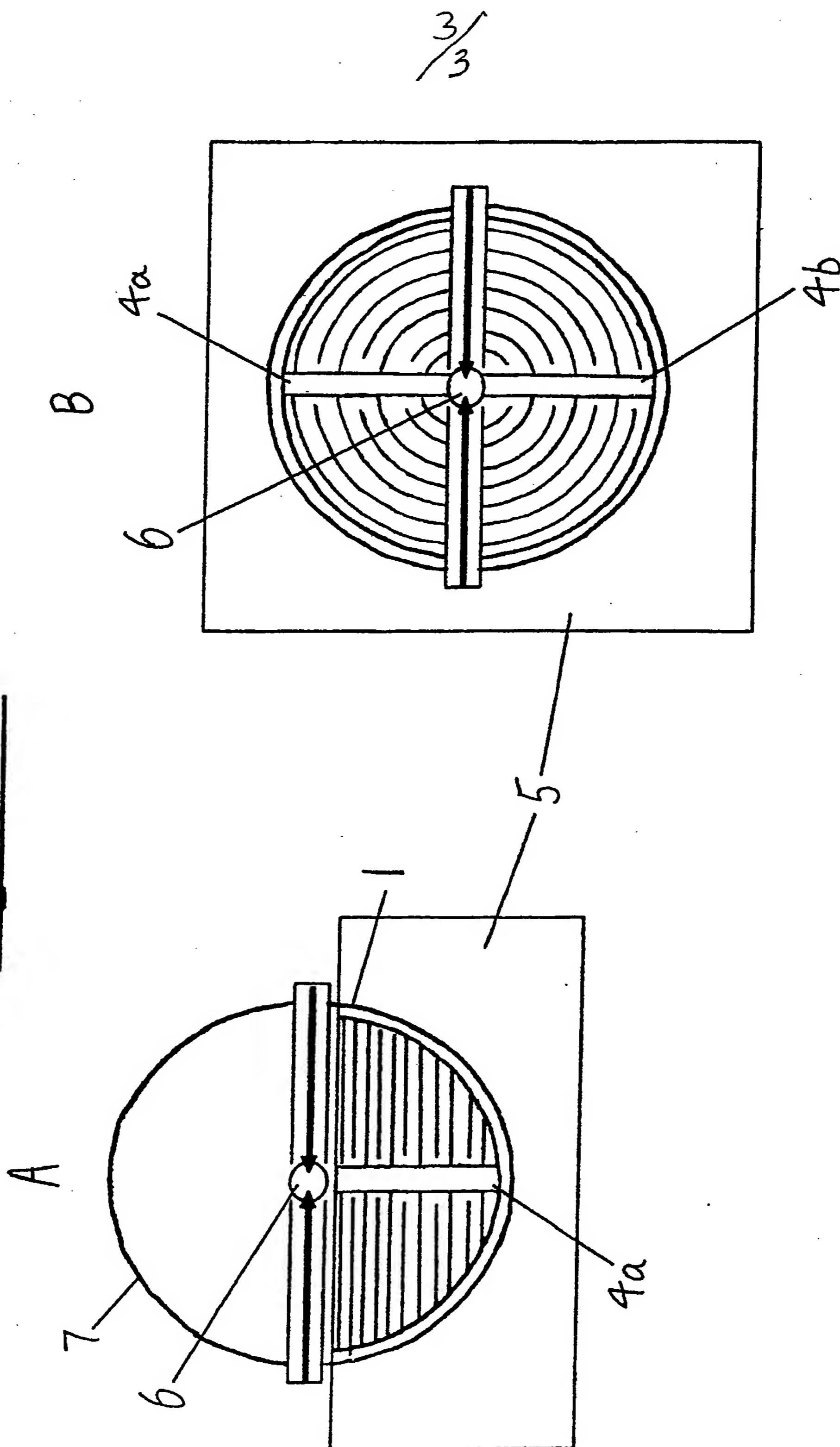


Figure 3



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High current photosensitive electronic switch

This invention relates to an electronic switch comprising a photosensitive semiconductor, in particular such a switch designed to carry currents of high magnitude.

The chemical composition of the switch of this invention is similar to the composition of the switches in British Patent Applications 8905910.9 and 9018957.2, but the switch according to this invention has at least the following two fundamental differences:

1. The switch described herein is specifically designed to be able to carry high currents at relatively low voltages. For instance such a switch may typically carry a continuous current in excess of 10 amps and have a maximum voltage rating of 5kV. Application 9018957.2 mentioned above has as an object to provide a photosensitive switch with a voltage rating greater than 30kV but with a current carrying capacity less than 0.2A. This difference makes the switch described herein particularly suitable as a high power switch.
2. While the switches of the two applications mentioned above use LEDs as a light source, the switch of the present invention uses an intense source of illumination having a very fast rise time on

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illumination. Preferably the source generates intense narrow band emission matched to the characteristics of the photosensitive material. Alternatively a source generating broad band emission which generates emission at the required narrow frequency band may be used. The light source is also specifically positioned with respect to the photosensitive material so as to utilise the light produced more efficiently.

An important feature of this invention is the geometry of the switch electrodes on the photosensitive layer. This geometry is substantially different from that of the switches mentioned above and is specifically designed to maximise current flow between the electrodes and enhance heat dissipation from the photoconductive layer.

The geometry of the electrodes is designed such that each electrode has a long perimeter which is closely spaced from the other electrode. When compared with more conventional electrode geometry whereby two substantially rectangular electrodes are positioned on the surface of a semiconductor layer relatively distant from each other it will be seen that the geometry according to this invention both decreases the distance across which current must flow from one electrode to the other and widens the available current path. Both of these factors act to reduce the resistance between the electrodes, thus permitting a high current flow. Typically the spacing between the electrodes is of the order of 2 mm.

Thus there is provided, according to the present invention, an electronic switch comprising a photosensitive semiconductor, two electrodes arranged on the surface thereof, and a light source which when actuated illuminates the semiconductor and causes the latter to provide a conductive path between the two electrodes, wherein

the photosensitive semiconductor is a

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sintered mixture comprising, by weight, 58-72% cadmium, 14.8-21% selenium, 7-15% tellurium, 7-12% sulphur, 0.1-1% chlorine and 0.005-0.1% copper; and

the geometry of the electrodes on the semiconductor is such that each electrode has a long perimeter portion which is closely spaced from the perimeter of the other electrode.

Preferably the semiconductor forms part of the inner surface area of a hollow sphere, at the centre of which is the light source. Such an arrangement maximises the efficiency with which the light from the light source utilized.

A further preferred feature is that the electrode on the surface of the semiconductor should be inter-digitated. This arrangement achieves the aim of having a long portion of the electrode perimeters in close proximity while also enabling the overall device to be relatively compact.

In order that the present invention be more fully understood a preferred embodiment will be described, as will the construction thereof, by way of example, with reference to the accompanying drawings, in which:

Figure 1 shows a section through a partially complete electronic device according to a preferred embodiment of this invention;

Figures 2A and 2B show respectively plan and section views of a part of a device according to Figure 1 in order to illustrate the electrode pattern; and

Figures 3A and 3B show respectively section and plan views of a complete electronic device according to the embodiment of Figure 1.

Throughout the figures and in the following description the same reference numerals correspond to the same parts of the device.

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In general terms, the device as illustrated in the figures comprises a high alumina hemispherical shell 1, on the inside of which is formed a sintered photosensitive layer 2 composed of the complex cadmium compound mentioned above. The alumina hemisphere 1 is fitted into a hemispherical cavity of an aluminium block 5 which acts as a heat sink. The illumination source 6 is positioned as shown in the centre of the circular perimeter of the alumina hemisphere. A hemispherical reflector 7 is positioned over the top of the alumina hemisphere to complete the hollow spherical cavity and to ensure that all of the illumination produced by the light source 6 falls onto the photosensitive layer 2. The electrodes 4a, 4b consist of inter-digitated concentric rings 4a', 4b' formed on the surface of the photosensitive layer 2 and are separated by a small distance, typically 2 mm.

The device described shows an illuminated conducting resistance of less than one ohm and a dark non conducting resistance greater than 15 million ohms. Continuous current carrying capability is greater than 10 amps and the device can cope with surge currents in excess of 100 amps. The maximum voltage and power ratings are 5000 volts and 100 watts respectively. The quoted ratings of current and power are very conservative estimates and it is expected they will be increased by many orders of magnitude with further development work.

The fabrication of the photoconductor device illustrated requires four basic stages, as follows:

- Stage 1: Preparation of materials;
- Stage 2: Application of the mixed materials to an electrically insulating surface to form a layer;
- Stage 3: Sintering the layer to produce a polycrystalline photosensitive layer;

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Stage 4: The attachment of electrical contacts to the sintered layer.

Each of these stages will now be described in detail.

Stage 1

The materials used in this process must be of the highest purity i.e. 99.999% or greater for the process to be successful. It is also desirable that the materials should be in the form of fine powders of particle sizes less than 3um.

For this particular example the following materials are used;

Cadmium Selenide	(Cd.Se)
Cadmium Sulphide	(Cd.S )
Cadmium Chloride	(Cd.Cl)
Copper Chloride	(Cu.Cl)
Tellurium	(Te)
Turpineol	(C H O) Organic Solvent
Ethyl Cellulose	(Organic binder)

Each of the non-organic powders are first mixed in the following proportions by weight for this particular example.

Cadmium Selenide	40.3%
Cadmium Sulphide	40.7%
Cadmium Chloride	8.9%
Copper Chloride	0.1%
Tellurium	10.0%

The proportions of contents may be used to adjust the electrical behaviour of the device but do not deviate from the basic range of compositions outlined above.

The powders are first mixed and then ground dry in a mechanical grinder such as a microliser, to ensure that they are completely mixed and no caking occurs. Examination of the mixed and ground powders at

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this stage should show that all of the particles are less than 3 um in diameter.

Stage 2

Having prepared the mixed powders, the next step is to convert the mixed and ground powder into a suspension that is suitable for spraying onto the inside of an electrically insulating high alumina ceramic hemisphere 1 shown in Figure 1. The hemisphere 1 is typically composed of 96% high alumina ceramic of 10 cm diameter and wall thickness of 0.5 mm.

To prepare the suspension the powder is mixed with a suitable liquid and binder to hold the particles together when the sprayed layer is dried. The liquid chosen for this task is TURPINEOL and the binder ETHYL CELLULOSE.

To convert the powder into a suspension suitable for spraying the Ethyl Cellulose is first dissolved in Turpineol in the proportions by weight of 10% and 90% respectively. The resulting solution is then mixed with the powder in proportions of approximately 25% solution to 75% powder to form a thick smooth liquid, the exact proportions cannot be stated since deciding the correct viscosity is largely a matter of personal judgement. The suspension is then ready for spraying onto the inside of the hemisphere.

The high voltage resilience of the photoconductive layer can be enhanced and irregularities in the thickness of the layer which may produce non-uniform electric fields may be compensated for by fabricating the layer over the top of a layer of electrical stress relieving material 3, previously formed on the surface of the alumina substrate. This layer must be chemically stable up to a temperature of 600°C to minimise chemical interaction between the stress relieving layer and the top layer of

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photosensitive material. For example the layer 3 may be silicon carbide powder bound together with an electronically insulating vitreous glaze which also binds the powder to the substrate. The electrical characteristics of this layer are determined by the size of the grains, density, thickness and dimensions of the layer. Typically the electrical characteristics for a 15 um thick layer of the type used in this device is that if the electrical field strength exceeds 25 kV/cm then the layer begins to rapidly conduct current. This prevents the formation of localised high electrical field domains.

Prior to spraying of the photoconductive layer 2 onto the inside of the high alumina hemisphere 1, a suspension composed of silicon carbide powder and vitreous glaze is sprayed onto the inside surface of the hemisphere to a thickness of 25 um. The stress relieving layer 3 is then fired at 900C to form a uniform hard glass like layer approximately 15 um thick, containing particles of silicon carbide.

The suspension containing the photoconductive material is next sprayed onto the surface of the first stress relieving layer 3 to a thickness of approximately 25 um. The hemisphere 1 onto which the layer has been sprayed is next placed in an oven and heated to 100°C for 10 minutes to evaporate off the solvent (TURPINEOL), leaving behind the ETHYL CELLULOSE which binds the particles of the powder together producing a uniform layer 2 that adheres to the stress relieving layer 3.

Following this final step in stage 2 the alumina hemisphere 1 and layers 2,3 can be safely handled and stored if necessary and is now ready for sintering.

### Stage 3

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The sintering stage consists of placing the hemisphere 1 and layers 2,3 in an enclosed Pyrex (Trade Mark) glass vessel into which nitrogen is passed at a slow rate and to which a small controlled percentage of oxygen in the form of air is added. Typically flow rates are 4 to 6 litres an hour, the nitrogen and other gases given off by the sintered layer are vented through a small hole in the lid of the vessel. Pyrex glass was found to be the most suitable material for the vessel. Other materials such as stainless steel or fused silica are attacked by gases released from the layers and hence are unsuitable.

A special electrically heated tube furnace may be used for the purpose of sintering the layers of photosensitive material. However most types of electrical furnace may be adapted provided they produce uniform heating of the substrates.

The layer 2 sprayed onto the inside of the hemisphere 3 is placed in the Pyrex glass vessel and the lid put in position, which is not a gas tight fit to allow the free passage of nitrogen through the vessel. Gas is directed into one end of the vessel through a Pyrex glass tube and passes through the vessel and vents from the opposite end. Prior to heating pure nitrogen is first passed into the vessel for a period of 20 minutes to purge out the bulk of the air that is initially present. The furnace and vessel are then brought up to a temperature of 520°C over a period of 50 minutes and pure nitrogen is allowed to continue to pass through the vessel during this period to ensure air does not enter the vessel. Once the vessel has risen to the required temperature a controlled percentage of air is added to the pure nitrogen to allow controlled absorption of oxygen into the layer 2 during the sintering process. For the

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composition described above the proportion of nitrogen to air is 97 to 3 and the total mixed gas flow is limited to 4.5 litres per hour. Furnace temperature is then maintained at 520°C for 10 minutes, with the gas flow being maintained during this period. At the end of the 10 minutes the furnace is turned off and allowed to cool over a time period of 60 to 90 minutes and air may be blown into the furnace to increase the cooling rate. The flow of mixed nitrogen and air is maintained until the temperature falls below 150°C.

The mixing of air with nitrogen during the sintering process has a profound effect on the photo-sensitivity and dark conductivity of the layer 2. If too much oxygen is allowed to enter the photoconductive layer 2, photo-sensitivity is lost but this property can be restored by heating the material again in a vacuum.

The sintered layer produced by the heat treatment described above is firm, adherent and chemically stable. During the sintering stage, approximately a 40% reduction in the thickness of the layer 2 takes place. Electron microscope studies of the surface shows that the sintered layer consists of large grains of approximately 9 um fused together at the boundaries.

Analysis of the layer 2 shows that the finished compositions are similar to those detailed in specification 9018957.2

The composition ranges are listed below. Under the heading "Process" are the compositions of the starting mixes and under "Product" those of the finished layer 2:

Process

CdSe	32 - 47%
CdS	32 - 47%

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CdCl	4.7 - 13%
CuCl	0.01 - 0.1%
Te	7 - 15%
<u>Product</u>	
Cd	58 - 72%
Se	14.8 - 21%
S	7 - 12%
Cl	0.1 - 1%
Cu	0.005 - 0.1%
Te	7 - 15%

Figure 1 illustrates a section through hemispherical shell 1 at this stage, showing the photosensitive layer 2 and the preferred feature of the stress relieving layer 3.

#### Stage 4

Following the removal of the hemispherical shell 1 and photosensitive layer 2 from the furnace the electrodes 4a,4b may be established on the surface of the photosensitive layer 2. The geometry of the electrodes is such that it maximises the length of the electrodes' perimeters which reduces the illuminated resistance of the switch and increases the current carrying capability. This is achieved in this embodiment by forming the contacts as a set of inter digitated narrow concentric fingers 4a',4b' separated by, typically, a 2 mm gap (for operation at 5000 volts) as illustrated in Figure 2. The fingers 4a' are part of electrode 4a, and the fingers 4b' are part of electrode 4b.

In order to establish the electrodes on the photosensitive layer, a metal hemispherical mask with 1 mm slots cut into a shape that allows the formation of such a set of inter digitated contacts is positioned over the surface of the photosensitive layer 2. Indium is first evaporated through the slots of the

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hemispherical mask which screens the surface of the layer, to a thickness of 0.1 um. Silver is then evaporated through the same mask over the top of the indium to a thickness of 0.5 um to improve the electrical conductivity of the inter digitated contacts. The mask is then carefully removed from the photosensitive layer 2. Following this procedure the hemisphere of alumina 1 on which the photosensitive layer 2 and the electrodes are deposited is placed in an oven and heated to 160°C for 5 minutes to allow fusion of the indium into the surface of the layer 2. Care must be taken to ensure that only the indium diffuses into the surface and not the covering of silver which may effect the properties of the photosensitive material 2.

The photoconductive layer produced by this process and this particular geometry of contacts, produces a dark resistance between the electrodes 4a, 4b of at least 5 million ohms in complete darkness and a resistance of 250 ohms is exposed to 2,500 Lux of light from a tungsten lamp.

#### Assembly of the Switch

Since this type of switch is intended for high current applications it is desirable that the illuminated resistance for this application should be less than 1 ohm. For this purpose a xenon flashlamp is used in this embodiment as the illumination source.

The term flashlamp refers to a type of light producing source that emits optical radiation by ionisation of a gas when excited by an electrical field. Such lamps are frequently used to "pump" laser tubes. It is usual to power this type of lamp by discharging a capacitor across the two electrodes of the lamp and to express the optical radiation emitted, in terms of Joules of energy.

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Flash discharge tubes such as xenon are preferred in this invention as they offer an economic means of generating an intense source of illumination. Conversion efficiencies of 60% are possible with rise times of a few micro seconds, and emissions of hundreds of joules for milliseconds are possible for high power types. The broad band emission from a xenon flash tube is suited to many types of photoconductor and extends from 200 nm to greater than 1000 nm of the electromagnetic spectrum. Hence the use of this type of illumination source in this invention allows the photoconductive material to be exposed to very high levels of illumination, producing relatively high conductivity in the photoconductive material. However the disadvantage of the flash tube is that all types have a finite lifetime that limits the switch to several hundred million switch operations. Thus it is envisaged that the flash tube may be replaced with light emitting diodes in further embodiment of the invention.

The type of tube selected for this particular embodiment is a short arc pulsed xenon lamp capable of producing 0.75 J per flash of optical energy at a rate of 50 per second.

The alumina hemisphere 1 with the photosensitive coating 2 is located into the hemispherical cavity of a block 5 of a metal, e.g. aluminium or copper which acts as a heat sink. A coating of heat conductive grease is first smeared onto the outer surface to ensure a good thermal contact between the hemisphere 1 and the surface of the cavity. The inside of the hemisphere may be filled with an electrical insulating fluid such as a liquid fluorocarbon to prevent electrical flashover between the electrodes 4a, 4b and improve thermal distribution.

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The xenon flash tube 6 as described above is then positioned so that the short arc inside the tube is exactly central in the circular perimeter of the hemisphere. The top, which is a hemispherical reflector 7, is then placed over the top of the alumina hemisphere. Figure 3 illustrates the complete device according to this embodiment in which the light source 6 and photosensitive material 2 are inside a hollow spherical cavity.

#### Optical Characteristics

Peak optical response is at 680 nm but shows 10% of peak response at 830 nm and 20% of peak at 560 nm, showing a reasonable wide band which approximately corresponds to the illumination produced by the xenon flash tube.

#### Electrical Properties

##### Dark Conditions

For a DC voltage of 5,000 Volts applied across the photosensitive layer contacts a current of less than 240 uA is expected, implying a switch dark resistance of greater than 16 mega ohms.

Electrical breakdown of the photosensitive material occurs at 5,5000 to 6,000 volts, from tests conducted on several samples with similar contact gaps, FOR A DC APPLIED VOLTAGE.

##### Illumination Source

Xenon flash tube emitting illumination in the range 200 nm to 1000 nm of the spectrum at a rate of up to 50 flashes per second and energy of 0.75 J per flash over a 10 ms period.

##### Time response Test

If a 10 volt DC bias applied across the photosensitive layer contacts the xenon flash tube according to that specified in the previous section, pulses of current will be generated in the 10

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volt bias circuit.

The characteristics of these pulses will be as follows;

Peak Current 17.5 Amps

Time from minimum current to maximum current where zero time marks the beginning of the illumination flash 4.7 us

Time for the current to fall to 1% of the peak value following termination of the optical flash 9.7 us

Estimated minimum resistance 0.57 ohms

Advantages Compared to Other Electronic Switching Devices

1. The voltage rating of the switch is much greater than other types of semiconductor switching devices.

2. Unlike other high power semiconductor switch types the voltage drop across the device when it is conducting can be arranged to be less than 1 volt.

3. Complete electrical isolation between the drive circuit and the switching device.

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CLAIMS:

1. An electronic switch comprising a photosensitive semiconductor, two electrodes arranged on the surface thereof, and a light source which when actuated illuminates the semiconductor and causes the latter to provide a conductive path between the two electrodes, wherein

the photosensitive semiconductor is a sintered mixture comprising, by weight, 58-72% cadmium, 14.8-21% selenium, 7-15% tellurium, 7-12% sulphur, 0.1-1% chlorine and 0.005-0.1% copper; and

the geometry of the electrodes on the semiconductor is such that each electrode has a long perimeter portion which is closely spaced from the perimeter of the other electrode.

2. A switch according to claim 1 wherein the electrodes on the surface of the semiconductor are interdigitated.

3. A switch according to claim 1 or 2 wherein the electrodes are formed of indium and silver.

4. A switch according to claim 1, 2 or 3 in which the semiconductor is in the form of an adherent layer on an electrically insulating substrate.

5. A switch according to claim 4 wherein a stress relieving layer is provided between the electrically insulating substrate and the sintered semi-conductor layer, the stress relieving layer being adherent to the substrate and being a fused mixture of a finely divided non-linear resistive material and an

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electrically insulating vitreous glaze.

6. A switch according to claim 5 wherein the non-linear resistive material is silicon carbide.

7. A switch according to claim 4, 5 or 6 wherein the semiconductor layer and the substrate and the stress relieving layer, if present, form a hollow hemisphere.

8. A switch according to claim 7 wherein the light source is arranged substantially at the centre of the circular perimeter of said hemisphere.

9. A switch according to claim 7 or 8 further comprising a hollow hemispherical reflective cover, which in conjunction with said hollow hemisphere forms a hollow spherical cavity.

10. A switch according to to any preceding claim wherein the light source generates intense electromagnetic emission at a frequency to which the photosensitive semiconductor is responsive.

11. A switch according to claim 10 wherein the light source is a xenon flashlamp.

12. An electronic switch substantially as hereinbefore described with reference to the accompanying drawings.

**Patents Act 1977****Examiner's report to the Comptroller under  
Section 17 (The Search Report)**

17

**Application number**

9107376.7

**Relevant Technical fields**

(i) UK CI (Edition      X )      HIK (KEBB, KEBX, KED, KABC)

**Search Examiner**

N W HALL

(ii) Int CI (Edition      5 )      HOIL

**Databases (see over)**

(i) UK Patent Office

**Date of Search**

4 JUNE 1991

(ii)

WPI Online

**Documents considered relevant following a search in respect of claims**

1-12

<b>Category (see over)</b>	<b>Identity of document and relevant passages</b>	<b>Relevant to claim(s)</b>
Y	GB 2170653 A (SHARP) see particularly page 1 lines 40-42, 51; page 2 lines 30-37	1
Y	GB 2133641 A (INT RECTIFIER) see particularly figure 2; page 4 lines 40-44	1
Y	EP 0063422 A2 (HUGHES) see particularly page 2, lines 35- page 3 line 3	1

SF2(p)



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Category	Identity of document and relevant passages	Relevant to claim(s)

#### Categories of documents

X: Document indicating lack of novelty or of inventive step.

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A: Document indicating technological background and/or state of the art.

P: Document published on or after the declared priority date but before the filing date of the present application.

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&: Member of the same patent family, corresponding document.

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